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Creating Circular, Efficient and Symbiotic Cities: And How Higher Education Should Contribute to Create the Solutions that are Required

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Abstract

The 'Grand Challenges' of our times, like climate change, resource depletion, global inequity and the destruction of wildlife and biodiversity can only be addressed by innovating cities. This paper will analyse major options for innovating cities, main barriers for these innovations that are rooted in the paradigms of the experts running urban systems and educational reforms that might contribute overcoming these barriers.

Keywords

Urban innovation · Urban systems · Engineering paradigms · Paradigmatic change · Engineering education

Despite the options of tele-working, tele-trading and tele-amusing, that allow people to participate in ever more activities, wherever they are, people are resettling in cities at an unprecedented speed. The 'rurification' of society, that was forecasted based on the development of tele-working, did not occur.

Cities are potentially far more resource efficient than rural areas. In a city transport, distances are shorter, infrastructures can be applied to provide for

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essential services in a more efficient way and symbiosis might be developed between various infrastructures.

However, in practice, urban infrastructures are not more efficient than rural infrastructures. This paper digs into the reasons why the symbiotic options that are available in cities are not (sufficiently) utilised. The main reason for this is not of an economic nature: Infrastructure organisations are run by experts who are part of a strong paradigmatic community. Dependence on other organisations is regarded as limiting the infrastructure organisation's freedom of action to achieve its own goals. Expert cultures are transferred in education, professional associations and institutional arrangements.

By three concrete examples of urban systems, the paper will analyse how various paradigms of experts co-evolved with evolving systems. The paper reflects on recent studies that identified professional education as the initiation into such expert paradigms. It will thereby relate the lack of urban innovation to the monodisciplinary education of experts and the strong institutionalised character of expertise.

1 Introduction, the Importance of Focussing on the Environmental Efficiency of Cities

The 'Grand Challenges' of our times, like climate change, resource depletion, inequity in a global community, and the destruction of wildlife and biodiversity require drastic measures. Marginal improvements that diminish resource consumption (and therefore also waste generation) by only a few percent, are very important, but by themselves insufficient to create the leaps in resource efficiency that are required. Radical innovations are important (Moors and Mulder 2002; Mulder 2007; Weaver et al. 2000) as well as processes of more encompassing societal change (Geels 2002; Rotmans et al. 2001; Grin et al. 2010).[1]

In this paper, the argument will be made that the dominant global trend of urbanisation should be made into an ally for Sustainable Development. The paper explores the potential of cities to become far more efficient in their metabolism. Such improvements cannot be achieved by the ordinary modes of innovation aimed at optimisation of existing systems. This paper will analyse barriers prohibiting sustainable innovations in cities. The expert communities that are running urban systems are identified as the main barrier to change: In three case studies, it is analysed how these communities developed institutionalised paradigms that prohibited innovations that exceed their systems. The paper reflects on changes in the education system to facilitate these innovations.

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[1] This paper results from a more encompassing project at THUAS regarding the Urban Metabolism.

2 Cities as a Key Challenge

2.1 Urbanisation

Throughout the world, people that live in rural communities are moving to large cities. In 1900, about 200 million people were living in metropolitan areas. Nowadays, this number has risen to more than 3.5 billion. It is expected that by 2050, there will be about 6.5 billion people living in metropolitan areas (UN Department of Economic and Social Affairs Population Division 2014). This urbanisation is far greater than the growth of world population.

This massive migration is in part determined by economic factors. Income is higher in cities and there are more opportunities for receiving education and health care. As consumption in cities is higher than in rural areas, this migration creates more resource consumption and more pollution.

This phenomenon is not just occurring in developing nations: It is not just a phenomenon of turning a resource driven (agricultural, mining) economy into an industrialised economy; the transition of industrialised economies into service and knowledge driven economies also fuels urbanisation. In 2050, more than 80% of the Europeans will live in cities, as compared to 70% today (UN Department of Economic and Social Affairs Population Division 2012).

This phenomenon is interesting as technological innovation plays a major role in it: Until about 10 years ago, many proponents of the information society claimed that the future would be purification or dis-urbanisation (Muhammad et al. 2008). The internet would imply that far more people would start tele-working, city cinemas and theatres were not needed anymore as one could watch movies and performances from the living room. Traffic jams would vanish and most people could enjoy the pleasures of a serene rural life. Reality unfolded differently….

This history is an interesting example of how technological communities ‘sell’ their new technologies: with attractive promises (van Lente 1993) that disregard the social embedding of technological practices. Telecommuting failed to realise its high ambitions by a disregard for the social aspects of working in an organisation, and the pleasure of going out cannot be replaced by watching a screen (Hynes 2014).

Urbanisation is driven on the one hand by the social practices by which labour as well as private lives are organised, and on the other hand the physical space that is needed for livelihood and/or well-being. The growing amount of social interaction involved in modern labour (e.g. knowledge society requiring more education and more team-work) as well as the growing amounts of capital accumulated in production and R&D facilities as well as the declining agricultural labour force explains the current urbanisation trends quite well (Primdahl et al. 2013).

2.2 Urban Systems and Urban Symbiosis as an Interesting Option

The densely populated urban areas create nodes of infrastructures that provide for important physical needs and services of the inhabitants:

- motorways, railways, (air-)ports, as well as undergrounds, tramways, busses, private cars and maintenance firms, provide transport
- district heating systems, gas grids, electricity grids, gasoline logistic systems, provide energy
- drinking water-, sewage-, MSW collection systems provide sanitation
- communication systems like fixed telephone lines, mobile telephone, Wi-Fi, cable tv, radio and tv broadcasting, provide communication
- and many more systems….

These systems are vital for urban life. A power black-out can threaten social order, and communications break down can have huge economic impacts (Takanashi et al. 1988; Schewe 2007; Frum 2000). These systems all have their own background and history. Many of them have a public utility character, which implies that their operation is often under public control.

Nowadays, as these systems are so densely present, the symbiosis between these systems can often be developed as follows:

– heat might be produced by heat pumps using drinking water wells, increasing the quality of the drinking water and providing heat.
– heat might be produced using the road surface, cooling the road; the same system might heat the road a bit in winter, preventing frost damage to the road and accidents.
– Sewage treatment systems might produce biogas for the gas grid, thereby decreasing the amount of residual sewage sludge.
– Electricity transformer stations might be cooled by heating (tap-) water
– Etc. (Cf. Mulder 2016b).

These options are only scarcely used, even if their commercial prospects appear bright. Sometimes it is argued that developing such symbiosis might create barriers for future innovation:

> If systems are combined/entangled, they are harder to adapt than the stand-alone systems. Symbiotic relations between systems might require more costs for future change, re-establishing the relation between systems and renegotiating mutual compensation, which might be blocked by a partner (Boons and Berends 2001).

However, it appears that developing symbiosis between systems also creates new options for innovation. The increased efficiency of symbiotic systems might enable the systems to fulfil additional tasks or develop additional improvements (Vernay 2013).

Hence, it seems that there are additional reasons that symbiosis between systems is not developed. In the remainder of this paper I will make the point that the disciplinary cultures of the experts running the infra systems play an important role. Experts controlling infrastructures rarely initiate any activity in regard to developing symbiotic relations with other systems. In fact, they prefer not to attract any attention from their controlling political authorities, except for some attention for the problem that their infrastructure solves. Civil engineers running Dutch coastal defences sometimes jokingly remarked "O Lord, give us our daily bread and every now and then a flood", as this would guarantee political support for their work for another decade. However, politicians were to be kept out of the decision-making regarding their systems. As a civil engineering professor once stated to his students: "you are rational, politicians are only out for re-election. Pay due attention to them and then neglect their words". This characterises very much the infrastructure operators—Operate the system rational. However, what does their rationality imply? What is rational depends on the goals that are to be achieved, and these should be set by the public authorities or managers that control the system. However, the controlling engineers have their own 'rationality'.

2.3 A Systems Culture of Autonomy

The emergence and growth of infra systems has been the subject of several studies after the ground breaking work of Hughes (1985). In their emergence and growth the organisations that built new systems, develop a strong inside–outside perspective. Hughes uses the military frontline as a model for the dynamics of a system—the system has to deal with external threats and barriers that prohibit the advance of the frontline. The systems are therefore aimed at annihilating 'reverse salients', i.e. removing the hostile strongholds that prohibit the growth of the system or create a threat to its continuity.

A system's culture emphasising autonomy can be recognised in many organisations that operate urban systems. It is generally reinforced by the institutional structure of such systems (being monopolistic entities) and the development of a professional culture for the experts that design, maintain and operate these systems.

3 Case Studies

3.1 Method

By the example of the electricity system, Hughes has analysed the dynamics of large (urban) systems and how these systems were institutionalised and were embedded in society. For the aim of this paper, it is important to understand, how the paradigms of the experts designing, running and maintaining these urban systems were created, transferred and institutionalised. This will be done using three historic case studies that will sketch the history of a type of urban system in combination with the history of paradigmatic community running this system.

3.2 Electricity Grids and Power Engineering

Power engineering is the discipline that deals with electric power networks. The specialists that operate these systems are generally educated as electrical engineers.

After Thomas Edison created the first electricity systems, the tremendous growth of electricity networks created a strong need for efficient electricity transmission, and for efficient electricity generation. As transmission of electricity could be carried out very efficiently by applying high voltages, power stations could become more efficient by becoming extremely large. Interconnections between power stations increased the reliability of the system and allowed for planned maintenance of power stations. These developments created large-scale centralised electricity systems that had a hierarchic nature. The paradigm of the experts that controlled these systems reflected this hierarchy:

Electrical engineering as a discipline emerged between 1890 and 1910 and was initially a homogeneous discipline, microelectronics did not exist and the extremely high voltages utilised in power engineering were still rather limited. As consumer electronics and microelectronics emerged, power engineering became one of the major sub-disciplines of electrical engineering. Power engineering now often is a special track of electrical engineering after engineering students master the basic science and mathematics of electricity. Power engineering has its own professional associations, its own standards and liabilities. Employers of power engineers are generally utilities, power stations, suppliers of equipment for the electricity grid and power stations, and related research institutes. Power engineering is an internationalised discipline with IEEE-Power and Energy being the main international professional body.[2]

In the 1970s and 1980s, power engineers were often fiercely resisting the introduction of renewable electricity generation by PV and wind turbines. The main argument for this position was that these sources of power could not be controlled by the grid operators. Thereby, the supply of this power to the grid would be out of tune with the 'alternating currents in the grid', or in electrical engineering terms, it would generate a lower power factor in the grid (i.e. increasing electricity losses). Central control for optimal grid performance was a key element of the power engineering's paradigm (Hughes 1985).

However, there is no compelling need to turn to hierarchy: reaching efficient decentralised power generation can be defined as a challenge for further innovation. But in practice, the power factor argument was turned into an argument not to move in the direction of renewable power generation. This was often combined with other

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[2] http://www.ieee-pes.org/.

professional prejudices, i.e. that windmills were a relic of the past. The paradigmatic change occurred, (towards a more ‘market type’ model of electricity production and consumption) but the change of paradigm is far from being completed.

3.3 Sewage Systems and Sanitary/Wastewater Engineering

Nineteenth-century cities were dirty places. Drinking water was often taken from waters that also were used to drain excrements from cities, or it was taken from wells that could be contaminated (e.g. by the content of cess pits). In the nineteenth century, various excrement collection systems were introduced for sanitation purposes: barrel-collection, vacuum systems and flushing systems. In the early twentieth century, the flushing system became dominant. In a flushing system, both sewage and the precipitation that have to be drained from the city, are both removed by the same pipes and released in open waters. This implied that the use of human excrements in agriculture was impossible. Imports of cheap fertiliser from South America, and the development of synthetic fertiliser had terminated the need for human excrements as fertiliser.

Sanitary engineering emerged as a new sub-discipline of civil engineering, and it was focussed on urban sanitary conditions. Hydrology and urban planning were created as the conceptual base of sanitary engineering. The robustness of the system became a cornerstone of its design, as any change of the system was complicated, risky and expensive.

Sewage systems greatly contributed to public health. However, sewage outlets created tremendous water pollution problems, especially if no sea coast or large river was present. But even cities at the sea coast had large problems. In nineteenth century, The Hague, for example, emitted its sewage in front of its beaches which was devastating for tourism. The outlet was two times shifted further offshore. The city’s engineers who had been raised in the paradigm of cheaply removing dirt from the city removed it ever further. Finally, it led to a conflict between cost efficiency and environmental performance: an elementary form of sewage treatment was introduced in 1960. In the 1980s, full treatment was introduced by national legislation (Mulder 2016a). This marked a change in paradigm, from cost effective sanitation, to cost effective destruction of urban dirt.

From the 1990s, sanitation engineers were confronted with demands to recover energy and raw materials from sewage. As this often implied dealing with other systems (energy systems, resource users) there was not always much enthusiasm. Moreover, the sector was still struggling with a problem of the past. The double function of sewage systems, both removing excrements and precipitation, made waste water treatment inefficient. The waste water treatment plants were often cleaning rainwater, while in cases of extreme rainfall the treatment plants could not cope with it and emitted raw sewage to open water. As in the course of time, rainwater was increasingly removed separately, sewage treatment had the prospect of growing to overcapacity. So, the 'load factor' of these systems would decrease, which implied that every experiment would be a further threat to the existing system.

The paradigm of the sanitation engineers emphasised preventing system disturbances, as this created the main threat to a politically controlled monopolistic organisation. Environmental performance of the system was generally less important. In fact, sanitation engineers did a proper job when nobody noticed their system. Innovation occurred mainly if it diminished risks of system failure (e.g. quality of piping, etc.). Novelty implied risk and it was therefore avoided. Changes and extensions of the system were extensively planned.

3.4 Drinking Water Production and Distribution

Drinking water was first supplied by pipeline grids in antiquity. However, modern drinking water systems started in seventeenth-century London (Tomory 2015). Various other cities started their own drinking water supply networks in the eighteenth and nineteenth centuries. Drinking water networks were sometimes needed to supply sufficient water to cities, but more often, their 'raison d'etre' was the insanitary condition of most cities. Drinking water supplies were needed to deal with health risks. For example, during a large cholera epidemic in the Netherlands in 1866, it was discovered that the larger cities with a reliable drinking water supply suffered relatively few victims (Departement van Binnenlandse Zaken 1872). This created a strong incentive for creating drinking water supply systems. Over 200 local drinking water systems emerged in the Netherlands, some were private, but most of them were controlled by (combinations of) municipalities.

In the twentieth century, population growth and increased per capita water consumption created a need for large-scale drinking water grids and additional raw water sources. But the main challenge for drinking water engineers was not in their systems as such but in the threat to the systems raw material—the growing pollution of surface and ground water. This often necessitated to take water from more distant raw water sources: Besides enlarging their drinking water production systems, Amsterdam, Rotterdam and The Hague each had to invest in new water intake stations at the Rhine and Meuse rivers together with pipelines and large reservoirs (to be used in periods of drought and in case of industrial spills). New forms of pollution often threatened drinking water supply and many efforts were required for maintaining quality. This led to an 'almost natural' paradigm for drinking water engineering: increasing the scale of the systems, by which the costs of reaching more remote safe water sources could be shared. Moreover, drinking water systems had to be reactive in regard to new cases of pollution.

Drinking water engineers were hardly organised as an international discipline: the basic technologies were well understood, and the main challenges of drinking water systems were to react to new local challenges. The basic features of drinking water systems (centrally controlled water intake, purification and distribution) were never challenged. Drinking water was cheap, which implied that there was no stimulus for risky innovation.

This unchallenged position of the core elements of the drinking water systems' paradigm created certain openness for societal issues. For example, drinking water companies organised advertising campaigns to reduce water consumption.

An interesting example is the joint creation of a district heating company in the town of Culemborg, in the Netherlands. The local drinking water company created a joint venture with the new inhabitants of an eco-neighbourhood. This joint venture installed a heat pump at the water company's water wells that supplied heat to 230 dwellings. However, there was a different counterforce in this case. For a long time, many municipalities had aimed at integrating their utilities, mainly to increase administrative efficiency. However, the neo-liberal wind of the 1980/90s led to privatisations. In this political climate hesitatingly developed entrepreneurial plans for diversification of drinking water companies were often shelved (Vernay and Mulder 2015) in the wave of privatisation and mergers. Drinking water companies had to focus on core business and strengthen their performance in order to prevail in this turbulence.

4 Conclusions

4.1 Systems, Paradigms and Change

Change in dominant features of systems is both risky and can often only be carried out gradually. Hence all professional groups controlling urban systems developed a strong paradigm that aimed at controlling and preserving their system. Central control of the system was seen as the best way to make the systems' operations predictable and prevent disastrous systems failure by overload, etc. Central control was a means to prevent systems failure, but often became the core element of the paradigm of the systems' operators and designers.

Paradigmatic resistance against societal demands is not irrational; in all argumentations, the paradigm of the professional group emphasises specific values, like avoiding risk or the necessity of systems control. Risk avoidance and systems control might appear as universal values for technological systems development but so is the value of improving a system, or altering it to accommodate new societal requirements. Semi-rational arguments often occurred as follows:

- The argument that something 'is impossible' can never be proven, as history have shown so often that nothing can be absolutely excluded in the future.
- A serious argument against urban symbiosis measures is the 'load factor' of current systems: as current systems are often 'under used', why to introduce a new alternative system that will even increase the overcapacity of the existing system?

– Every change of system will lead to a destruction of existing assets, know-how and experience, i.e. the system is locked in.

Executing control seems to be the dominant feature of all the engineering paradigms. It is what Habermas called the ideological nature of science and technology (Habermas 1968).

4.2 Bridging Disciplines, Creating Solutions

It is often claimed that the challenges of Sustainable Development necessitate inter- and transdisciplinary research and design. But this applies not only to SD challenges. Engineering disciplines can do a better job if their control paradigm is loosened; instead of harnessing nature (an expression introduced by Mao Tse Tung) (Shapiro 2001), the engineers that control urban systems should learn to work with nature, and with others, by which more (and probably better) solutions might come in reach. Better solutions require thinking across the dividing lines of current systems, and thinking long term (Mulder 2014, 2017). That requires a great change, in engineering paradigms, in professional culture and in engineering education. But that will contribute to better solutions, not only for the grand challenges for which Sustainable Development is the answer but also for the challenges of the past for which various urban systems were the answer.

Such changes will not be accomplished overnight, they will take probably at least a generation as paradigmatic change is generally not a process by which individuals switch to new ideas, but a process by which a new generation, with new ideas, takes over (Kuhn 1962). But this implies that education has a crucial role to break the transfer of the old paradigm to new generations and to create openness to new challenges. Although it might be argued that a paradigm shift is required in a more general sense, this research specifically identifies the need for paradigmatic change among the experts that design and run urban infrastructures. That might change today’s strong trend towards urbanisation into a force supporting Sustainable Development.

It might also be important that more people engage regarding the challenges of sustainabilising urban infrastructures. These invisible structures are generally taken for granted by the public, which implies that they are also of no interest to politicians. How the ‘invisibles of the city’ can be turned into objects of citizen engagement is an issue for further research.

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